Population Characteristics of the Black Sea Bass *Centropristis striata* from the U.S. Southern Atlantic Coast

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ABSTRACT

We examined the age structure and status of the U.S. southern Atlantic stock of black sea bass, using recorded and estimated landings and size frequencies of fish from commercial, recreational, and headboat fisheries from 1979-1995. Estimates of annual, age-specific fishing mortality (F) for different levels of natural mortality (M = 0.2, 0.3, and 0.4 yr^{-1}) were obtained from annual landings in numbers at age by application of both separable and calibrated virtual population analyses (VPA). Fishery independent data from MARMAP hook-and-line and trap gears were used in the calibration procedure.

Mortality levels (F) ranged from 0.6 to 1.7 between 1979 and 1995 for fully recruited ages (4-7) (M = 0.3), while spawning potential ratios ranged from 44% to 60% based on mature female biomass and from 20% to 32% based on total mature (male and female) biomass from the separable VPA. Similarly, mortality levels (F) ranged from 0.6 to 1.5 between 1979 and 1995 for fully recruited ages (4-7) (M = 0.3), while spawning potential ratios ranged from 47% to 58% based on mature female biomass and from 21% to 31% based on total mature biomass from the calibrated VPA. Because black sea bass are protogynous hermaphrodites (transforming from females to males) and the effect of changes in population abundance on sex transformations is unknown, the percent reduction in males to females was estimated based solely on increased mortality by fishing. Thus, the use of spawning potential ratio based on total

mature biomass was used for comparison to biological reference points.

In spite of retrospective problems with overestimation of F (and hence underestimation of SPR) in the current year, declining recruitment, headboat CPE, and MARMAP Survey CPE beginning in the mid-1980's raise concerns about potential overfishing. Although the decline in recruitment may be largely environmentally driven, resultant lower productivity increases the risk of overfishing at this time.

Introduction

Black sea bass, Centropristis striata, also called blackfish, is a member of the family Serranidae and inhabits continental shelf waters, predominantly between Cape Canaveral, Florida, and Cape Cod, Massachusetts (Mercer 1989). Two populations are thought to occur along the Atlantic coast, separated by Cape Hatteras, North Carolina (Mercer 1989, Shepherd 1991). Black sea bass occur in depths of 2-120 m, but most adults are found in 20 to 60 m (Mercer 1989). Although black sea bass north of Cape Hatteras are migratory, movements of those south of Cape Hatteras are limited and less well-defined (Ansley and Davis 1981, Collins et al. **in press**).

Spawning for black sea bass occurs from January through June along the U.S. southern Atlantic coast, peaking from March to May (Mercer 1989). Wenner et al. (1986) also found ovarian activity in September and suggested a small fall spawn probably extending into October. They found mature gonads in none of the females at age 0, 48.4% at age 1, 90.3% at age 2, 99.1% at age 3, and 100% at all older ages. Black sea bass are protogynous hermaphrodites, but mature males occur in all age groups (Table 1). Because the transitional period is on the order of weeks to a few months, the transitional stage is combined with males for calculation of sex ratios used in the analyses that follow. Wenner et al. (1986) provided several relationships for estimating fecundity from length, weight, or age.

At the request of the South Atlantic Fishery Management Council (SAFMC), this analysis of the status of stock for black sea bass south of Cape Hatteras through the east coast of Florida was conducted to update that of Vaughan et al. (1995). The earlier analysis used commercial, recreational, and headboat data through 1990. The new analysis revises the historical data and adds five more years of fisheries-dependent data to the analysis. Also, the earlier analysis used only the uncalibrated separable virtual population analysis (SVPA) of Pope and Shepherd (1982). This new analysis, uses not only the uncalibrated separable approach, but also uses a calibrated approach based on ADAPT (Gavaris 1988).

In this report we compute and document changes in age structure and population size of black sea bass found off the eastern Atlantic Coast of the United States south of Cape Hatteras, North Carolina. Specifically, given age-specific estimates of instantaneous fishing mortality rates and information on growth, sex ratios, maturity and fecundity, analyses of yield per recruit (YPR) and spawning potential ratio (SPR) are used to determine status of the U.S. southern Atlantic black sea bass stock.

Methods

There are three fisheries for black sea bass: commercial, recreational, and headboat. The commercial fishery is principally prosecuted by blackfish traps and by hook-and-line, with some landings by trawl. The recreational fishery includes fishing from shore, and from private and charter boats. For sampling purposes, the headboat fishery (charter-type operations that charge recreational fisherman per person or "head") is considered separate from the recreational fishery. Annual catch (number and weight) and length data from these three fisheries, together with length at age information, permitted development of a catch-in-numbers-at-age matrix (or simply catch matrix) for 1979-1995.

Development of estimates of catch in numbers at age allows application of catch curve approaches either by year class or fishing year for estimation of Z. Independent estimates of instantaneous natural mortality (M), based on life history relationships (Pauly 1979, Hoenig 1983), permit estimation of instantaneous fishing mortality rates (F = Z - M). Separable and calibrated virtual population analysis (Doubleday 1976; Pope and Shepherd 1982, 1985; and Gavaris 1988) are used to reconstruct the estimates of annual age-specific population size and instantaneous fishing mortality rates (F) for 1979-1995.

Development of Catch-in-Numbers-at-Age Matrix

Data for development of the catch-in-numbers-at-age matrix for the study area of the U.S. southern Atlantic coast (Miami, Florida, to Cape Hatteras, North Carolina) come from several sources. Commercial fishery data are obtained from NMFS (Southeast Fisheries Science Center, Beaufort, NC, and Miami, FL) from the General Canvas data base (for catch statistics, 1972-1995) and from the Trip Interview Program (TIP) data base (for length and weight statistics, 1983-1995). Recreational catch estimates and length and weight information are obtained through the Marine Recreational Fisheries Statistics Survey (MRFSS) data base (NMFS, Washington, DC) for 1979-1995. Headboat catch estimates and length and weight sampling data are obtained from NMFS (Southeast Fisheries Science Center, Beaufort, NC) for 1975-1990. Fishery-independent length, weight and age data from commercial gears (hook-and-line and several types of traps, 1979-1995) are from the MARMAP (Marine Resources Monitoring, Assessment, and Prediction) Program (South Carolina Department of Natural Resources, Charleston).

Estimation of catch in numbers at age is the same as in Vaughan et al. (1995). The basic approach consists of multiplying the catch in numbers (n, scalar) by an age-length key (A, matrix) by a length-frequency distribution (L, vector) to obtain catch in numbers at age (N, vector):

$$N_{ax1} = n \cdot A_{axb} \cdot L_{bx1}, \qquad (1)$$

where a is the number of ages (e.g., ages 0 to 8+ years) and b is the number of length intervals (e.g., 1 inch increments from 2 inches to 20+ inches). If catch is available only in weight (as is the case with commercial landings), then catch is converted to numbers by dividing catch in weight by mean weight per fish landed for the same fishery/gear, time period (annual), and geographic region (U.S. southern Atlantic coast). Length data for a given fishery/gear is converted to weight by a weight-length relationship and the average mean weight per fish for that fishery is calculated annually.

<u>Historical Landings</u>. Adjustments are necessary to obtain commercial landings for the area of interest. Because all black sea bass caught north of Cape Hatteras are assumed to belong to a separate stock from that south of Cape Hatteras, North Carolina commercial landings needed to be divided at Cape Hatteras. As in Vaughan et al. (1995), all reported fish trawl landings (NMFS gear code 210, General Canvas data) from North Carolina are assumed to have taken place north of Cape Hatteras (although some catches from north of Cape Hatteras are landed south of Cape Hatteras), while reported landings from all other commercial gears (mostly traps and hook-and-line) are assumed to take place south of Cape Hatteras (Nelson Johnson, NMFS Beaufort Laboratory, Beaufort, North Carolina, pers. comm.). To obtain annual landings in numbers by gear from annual catch in weight by gear, landings in weight by gear (General Canvas data) are divided by mean weight of fish landed by that gear (TIP data).

Estimates of the recreational catch statistics in weight and numbers are obtained from the Marine Recreational Fishery Statistics Survey conducted from 1979 through 1995 (Gray et al. 1994; **http://remora.ssp.nmfs.gov/index.html**). Three catch types are defined for the recreational fishery: **Type A** refers to catches that are available for identification and measurements; and **Type B** refers to catches that are not available for identification or measurement. The latter category is subdivided into: **Type B1** catches, used for bait, filleted, discarded dead, etc.; and **Type B2** catches, released alive. A relatively large percentage of the catch was type B (64%: 8% Type B1 and 56% Type B2) for black sea bass for the period 1991-1995, similar to recent levels of Type B2 caught fish in the south Atlantic red drum recreational fishery (Vaughan 1996). We used a 5% post-release mortality (Bugley and Shepherd 1991) to include a portion of the type B2 fish in the landings, although Collins (in press) concluded that post-release mortality varied with depth and could be much greater than 5%.

Two additional adjustments are required before the recreational catch data could be incorporated into the catch-at-age matrix. North Carolina recreational catch estimates for the area north of Cape Hatteras, and headboat catch estimates from 1979 through 1985 (duplicated with a separate headboat sampling program), had to be subtracted from total recreational catch. The MRFSS provided post-stratified estimates of black sea bass landings north and south of Cape Hatteras for the state of North Carolina (see http site above). Intercept sampling for length is assumed proportional to catch for separating headboat from party/charter boat modes.

Headboat landings for the period 1979-1985 are adjusted by state. About 1293 of the 1306 intercept samples (e.g., length measurements) in Florida identified under the combined charter/headboat mode are from headboats, so about 99% of the landings for this mode are estimated as from headboats, and the remaining 1% from charter boats. Similarly, an estimate of about 50% of the charter/headboat mode landings in Georgia are from charter boats, 20% in South Carolina, and 19% in North Carolina (south of Hatteras) based on intercept samples.

Headboat landings are estimated from the NMFS Beaufort Laboratory sampling program (Dixon and Huntsman, in press). To aid in distinguishing from charter boats (sampled by MRFSS), which ordinarily charge by the trip, the working definition for headboat is any vessel that usually carries 15 or more passengers regardless of manner of payment. Headboat landings in weight and numbers are available for North and South Carolina from 1975 through 1995. All North Carolina headboat landings are from south of Cape Hatteras, so no adjustments were needed. Estimated landings for northeast Florida (south to Sebastian) are available from 1976 through 1995, and for southeast Florida (from Fort Pierce through Miami) from 1981 through 1995.

Total headboat effort in angler days and catch of black sea bass in weight per unit effort are available for the same time period (1975-1995 for North and South Carolina, 1976-1995 for northeast Florida, and 1981-1990 for southeast Florida). Catch per effort (CPE) is calculated by dividing catch in numbers by effort in angler days.

Weight is related by power function to total length for U.S. southern Atlantic black sea bass collected from the three fisheries. Fishery-specific relationships, combined with the appropriate length frequency data, are used to estimate mean weight for a given fishery/gear/year. These regressions are conducted in a weighted manner, weighted by catch in numbers over subsets of time (seasonally or by 2-month wave) and area (generally by states).

Length Frequency Distributions. Commercial length and weight data are available from sampling of commercial landings through the NMFS Trip Interview Program (TIP) database between 1984 through 1995 from North Carolina through the east coast of Florida. Only North Carolina data are available for 1983. North Carolina fish trawl data were eliminated from consideration because we assumed they came from catches made north of Cape Hatteras.

Annual length frequency distributions for commercial hook-and-line, traps and trawls (from other than North Carolina) are available from 1983-1990. With trawl landings being minuscule and few fish sampled (248), one overall length frequency distribution is used for all years 1979-1995. Because of low sample size (41) for commercial trap lengths in 1986, the mean length frequency distribution for the bracketing years (1985 and 1987) is used in its place. All length frequency distributions are weighted by catch in number caught during that gear, year, season (quarterly), and state.

The MARMAP Program collects standardized trap and hook-and-line data annually in the South Atlantic Bight (Collins and Sedberry 1991). The geographic scope of MARMAP is Cape Hatteras to Cape Canaveral, but with most sampling between Cape Fear and Jacksonville, Florida. The seasonal scope for reef fish sampling is late spring through summer (generally mid- to late April through September). The data used in this analysis come from several gears: Hook-and-line (1979-1995), Blackfish traps (1979-1989), Florida snapper traps (1980-1989), and Chevron traps (1988-1995). Length frequency distribution for black sea bass (measured in total length to the nearest centimeter) are estimated by gear for the years available.

As in Vaughan et al. (1995), MARMAP hook-and-line and blackfish trap length data are used to increase the number of years available for analysis. Because scientific sampling and commercial fishing serve different purposes, the MARMAP length frequency distributions for 1979-1983 could not be directly substituted for the corresponding missing commercial length frequency distributions. Median lengths calculated from the commercial and scientific hook-and-line and blackfish trap data sets are compared separately. No-intercept regressions are performed for each gear to develop scaling factors (1.28 ± 0.01 for hook-and-line and 1.14 ± 0.02 for blackfish traps) by which to multiply the pooled commercial length frequency distribution (1984-1988) for hook-and-line and traps. The length frequency distributions for these gears for 1979-1983 are generated from these scaling factor. Hence, the shape of the commercial hook-and-line and blackfish trap length frequency distributions are maintained, while using the relationship between MARMAP and corresponding commercial data for the same gear simply for scaling. The relationship between median lengths from commercial and MARMAP data is quite good for hook-and-line, and not as good for blackfish traps. Although the majority of commercial landings (67%) are by traps, commercial landings generally made up about a third of total landings during 1979-1983, so potential bias is minimal. Hence, annual length frequency distributions for the period 1979-1995 are available for each of the three gears (hook-and-line, traps and trawls) to use in developing the catch-in-numbers-at-age matrix.

Recreational length frequency distributions from the MRFSS data base are available from 1979-1995. All length frequency distributions are weighted by catch in number (A+B1) caught during that mode, season (2-month wave), and state. Headboat length frequency distributions from the MRFSS (1979-1985) are not used in the development of the catch-in-numbers-at-age matrix.

Annual headboat length frequency distributions from NMFS Beaufort Laboratory are available for the period 1974-1995. Only those from 1979-1995 are used in developing the catch-in-numbers-at-age matrix. All length frequency distributions are weighted by catch in number caught during that season (Jan-May, Jun-Aug, Sep-

Dec), and state (NC, SC, NE FL, and SE FL).

Age-Length Keys. Age-length data are from MARMAP program samples taken from the South Atlantic Bight during 1978-1995. Black sea bass were collected with a variety of gears, but primarily with blackfish traps, Florida snapper traps, and more recently Chevron traps (Collins 1990), and hook-and-line. Weights (nearest g) and lengths (total and standard, nearest mm) were recorded, and otoliths (sagittae) were removed and stored dry. Otoliths were examined whole under reflected light with a dissecting microscope, and age estimates were based on the number of opaque zones visible. Good evidence for the annual nature of these opaque zones (marginal increment analysis) was derived from a subset (1978-1981) of these specimens (Wenner et al. 1986).

Growth in total length as a function of age was fit to the von Bertalanffy (1938) growth equation using nonlinear regression with the Marquardt option (SAS Institute Inc. 1987). Initial estimates of the parameters were done using all available measurements from 1978 through 1995 with equal weights. Total length rather than standard, and inches rather than centimeters were used in the analyses because management measures such as minimum or maximum size limits are all based on total length in inches.

Estimation of growth parameters becomes a problem when large numbers of young fish and few old fish are available for fitting parameters (Vaughan and Kanciruk 1982). Only one black sea bass out of 17,918 was 20" or longer in total length. Hence, weighting by the inverse of the number of fish of each age was used to reduce the effect of the large numbers of younger fish and increase the relative weight of the few, older fish. This approach was applied to all data from the MARMAP sampling program (1978-1995) (all age 0 fish were deleted from consideration in curve fitting procedure).

Age-length keys (matrices) are needed to convert length frequency distributions to age frequency distributions. These keys were developed from the same MARMAP data used in estimating von Bertalanffy growth parameters (n = 17,918). The keys consist of the proportion of fish of each age sampled from a given length interval. For development of the catch-in-numbers-at-age matrix that follows, we first developed an overall age length key for 1978-1995 with total length divided into 1 inch increments from 2" to 20+" and ages 0 through 8+ years. Next, separate keys were developed for three temporal periods (1978-1985, 1986-1990, and 1991-1995). The first two temporal periods were those used in Vaughan et al. (1995). Finally annual age-length keys were developed for 1979 through 1995. When fewer than 10 fish were available for a given length interval, data were used from a key representing a time period of greater duration. Total lengths greater than 20" (one individual) and ages greater than 8 years (16 individuals) are pooled with lengths of 20" and 8 years, respectively.

Catch-in-Numbers-at-Age Matrix. Annual application of Eq. (1) to each fishery/gear (commercial hook-and-line, commercial traps, commercial trawls, recreational, and headboat) were performed separately and accumulated for each year to obtain annual estimates of catch in numbers at age for 1979-1995 (referred to as catch matrix). Eq. (1) was also applied annually to the MARMAP Survey estimates of black sea bass catch per effort (CPE) and corresponding length frequency data for each gear as available from 1979-1995 to obtain age-specific calibration indices (Hook-and-Line, and Blackfish, Florida snapper, and Chevron traps).

Mortality and Population Dynamics

Instantaneous total mortality rate (Z) was estimated from catch curve analysis (Ricker 1975) by year class (cohort) and fishing year from the fishery-dependent catch matrix. Estimates were obtained by regressing the natural logarithm of catch in numbers against age for fully recruited ages (descending right-hand limb, ages 4 through 7).

Natural Mortality. Pauly (1979) obtained the following relationship for estimating M based on growth parameters and mean environmental temperature:

$$\log_{10}M = 0.0066 - 0.279 \cdot \log_{10}L_{\infty} + 0.6543 \cdot \log_{10}k + 0.4634 \cdot \log_{10}T \qquad (2)$$

where M equals instantaneous natural mortality rate, L_{∞} (cm) and k (yr^{-1}) are parameters from the von Bertalanffy growth equation, and T (^{o}C) is mean environmental temperature. A temperature of $20^{o}C$ (Charles Wenner, South Carolina Marine Resources Research Institute, Charleston, pers. comm.) was used to represent mean nearshore temperature off of Charleston, South Carolina. Estimates of M based on Pauly's (1979) approach ranged from 0.2 to 0.6. Lower estimates of M are associated with higher estimates of L_{∞} and lower estimates of k.

Another life history approach suggested by Hoenig (1983) is based on the maximum age observed in the population. Because the relationship he developed is based on Z, instead of M, the maximum age in the unfished population (F=0; M = Z-F) would provide an estimate of M. The oldest fish in the MARMAP data set was age 10, yielding an estimate of M equal to 0.4. Higher ages provide lower estimates of M, suggesting that 0.4 should be viewed as a maximum. Reports of black sea bass as old as age 20 (SEFSC 1995) suggest a minimum estimate of M equal to 0.2. As in Vaughan et al. (1995), most of our analyses are based on M equal to 0.3, with additional analyses for M equal to 0.2 and 0.4.

Fishing Mortality. The catch matrix was interpreted using two different virtual population analysis (VPA) approaches to obtain annual age-specific estimates of population size and fishing mortality rates. Virtual population analysis sequentially estimates population size and fishing mortality rates for younger ages of a cohort from a starting value of fishing mortality for the oldest age (Murphy 1965). An estimate of natural mortality, usually assumed constant across years and ages, was also required. The separable method of Doubleday (1976) assumes that age- and year-specific estimates of F can be separated into products of age and year components. We used the FORTRAN program developed by Clay (1990), based on Pope and Shepherd (1982).

Additionally, we used a second method that calibrates the VPA to fishery-independent indices of abundance (Pope and Shepherd 1985). The specific calibration approach was that developed by

Gavaris (1988) and modified by Dr. Victor Restrepo (Cooperative Institute of Fisheries Oceanography, University of Miami, Miami, FL) as the program FADAPT. Indices for calibration were obtained from MARMAP data for hook-and-line and several traps (Blackfish, Florida snapper, and more recently Chevron traps).

The catch matrix analyzed consisted of catch in numbers for ages 1 through 7 and fishing years 1979 through 1995 (partial recruitment for age 0 black sea bass was essentially 0 for all years). For the SVPA, starting values for F were based on the mean of the final three year class (1987-1989) estimates of Z (1.0 yr^{-1}) and final F obtained by subtracting M from Z. Sensitivity of estimated F to uncertainty in M was investigated by conducting the above VPAs with alternate values of M (0.2 and 0.4). A starting partial recruitment vector for FADAPT was based on an SVPA run for the period 1990-1995 (this minimized the coefficient of variation based on several SVPA runs of varying duration with final year of 1995). Retrospective analyses were conducted for both VPA approaches to investigate the potential for bias in F for the most recent years by varying the final year used in the analysis from 1990 to 1995 (initial year was 1979 throughout). The difference between estimates of F from historical data (last year of catch matrix used was varied between 1990 and 1994) and from the full catch matrix (last year of catch matrix used was 1995) were compared.

Yield per Recruit. Equilibrium yield per recruit analysis was conducted based on the method of Ricker (1975), who subdivided the exploited phase into a number of segments (e.g., years) during which mortality and growth rates are assumed constant. This approach permits instantaneous natural and fishing mortality rates to vary during the fishable life span and permits a general growth pattern to be used. Total equilibrium yield per recruit is obtained by summing the catches in each segment over the total number of segments. Input data were based on both sexes and all years combined.

Spawning Potential Ratio. Gabriel et al. (1989) developed maximum spawning potential (%MSP) as a biological reference point. The currently favored acronym for this approach is referred to as spawning potential ratio (SPR). A recent evaluation of this reference point is given in a report by the Gulf of Mexico SPR Management Strategy Committee (1996) for the Gulf of Mexico Fishery Management Council (see also Mace and Sissenwine (1993), and Mace (1994)). Equilibrium SPR was calculated as a ratio of spawning stock size when fishing mortality was equal to the observed or estimated F divided by the spawning stock size calculated when F equal to zero. All other life history parameters were held constant (e.g., maturity schedule and age-specific sex ratios). Hence, the estimate of equilibrium SPR increases as fishing mortality decreases.

Comparisons of age-specific spawning stock biomass were based on mature female biomass, egg production, or even on total mature biomass (both males and females). To address the change in male to female ratio with increasing mortality, we estimate the reduction in the proportion of mature males to mature males and females in numbers compared to what that proportion would be when F equals zero.

We used the relationship between fecundity (E, number of eggs) and total length (TL, mm) based on the least-squares linear-regression equation ($r^2 = 0.62$, $n = 115$) (Wenner et al. 1986):

$$\log_{10} E = -0.605 + 2.335 (\log_{10} TL), \qquad (3)$$

to provide an alternative to female spawning stock biomass as a measure of spawning potential. Separate sex-based growth relationships were used for males and females in these calculations.

Results

Historical Data. For the study period (1979-1995), total landings in weight peaked at 3.6 million pounds in 1980, with lesser peaks of 2.9 million pounds in 1982, 2.8 million pounds in 1984, and 2.9 million pounds in 1988 (Table 2). Landings have been at or below 2.0 million pounds since 1990, with the low at 1.3 million pounds in 1995. Peaks in total landings in numbers were at 4.3 million in 1979 (4.2 million the following year), and 4.6 million in 1982. During 1979-1985, the landings by weight were 34% commercial, 40% recreational, and 26% headboat, with very similarly break out for 1986-1990 (35%, 42%, and 24%, respectively). However, during 1991-1995 commercial landings represented 49% by weight, recreational with 39% by weight, and headboat declining to 11% by weight.

Commercial landings in weight peaked in at 1.2 million pounds in 1981 and at 1.0 million pounds in 1990 (Table 2). Lows were at 0.6 million pounds in 1987 and 1995. Similarly, commercial landings in numbers peaked in 1981 at 1.4 million fish and again in 1990 at 1.5 million fish, with lows at 0.6 million fish in 1987 and 1995. Since 1985, commercial trap landings by weight made up about 67% of all commercial landings, with commercial hook-and-line landings making up about 32% and trawl the remaining 1%.

Recreational landings in weight fluctuated between 0.3 million pounds in 1981 and 1.5 million pounds in 1984, with values remaining below 0.8 million pounds for 1990-1995 (Table 2). Recreational landings in numbers during the period 1979-1995 generally declined from a high of 2.6 million fish in 1979 to 0.6 million fish (A + B1 + 5% B2) in 1995.

Similarly, headboat landings declined from a high of 0.7 million fish (weighing 1.2 million pounds) in 1982 to 0.2 million fish (weighing 0.1 million pounds) in 1995 (Table 2). Declining trends in headboat catch in numbers per angler days appear to be present for both North and South Carolina (Fig 1a), which together represent a large majority of headboat landings.

Declines in catch per effort (CPE) are also noted in indices based on MARMAP sampling using hook-and-line and traps (Fig. 1b). Trap effort was standardized by "soak time" and hook-and-line effort by "angling time" (Collins and Sedberry 1991). There is a precipitous decline in hook-and-line CPE between 1987 and 1988. Less drastic declines are noted in blackfish trap and Florida snapper trap CPEs during the middle to late 1980s. Unfortunately, both of these indices were discontinued after 1989, while the Chevron trap began use in 1988 with two years of overlap.

Growth in Weight and Length. The estimated relationship for weight (pounds, W) as a function of total length (in, L) used in all modeling applications is based on all fisheries-independent (MARMAP) data (n = 14,783):

$$\ln W = -7.09 + 2.78 \ln L, \tag{4}$$

where $r^2 = 0.97$ and mean squared error is 0.021.

Parameter estimates for the von Bertalanffy growth equation are summarized in Table 3. Different estimates of von Bertalanffy parameters for the three sex categories (female, transition, and male) do not necessarily reflect differences in growth. Because there were few old females relative to males (due to protogyny), greater difficulties in parameter estimation arose. However, sizes for the ages available for inclusion in regression adequately reflect those observed in the data, and were useful for representing the observed (though small) differences in size at age for the sexes in calculating spawning potential ratio.

<u>Trends in Mortality</u>. Instantaneous total mortality rate (Z) by year class (cohort) showed several peaks (1.8 for 1976 cohort, 1.9 for 1978 cohort and 1.8 for 1985 cohort) (Fig. 2). The lowest estimate was 0.6 for the 1989 cohort (with only ages 4-6). Estimates of Z by fishing year for the early period average 1.3 (ranging from 0.8 in 1979 to 1.9 in 1985). This average declined slightly for 1986-1990 to 1.2 (ranging between 1.0 in 1990 and 1.4 in both 1986 and 1989), and increasing again to 1.3 for 1991-1995 (ranging between 1.2 in 1991 and 1995 and 1.5 in 1992).

Annual age-specific estimates of F were obtained from the separable VPA applied to the catch matrix (Table 4) using both uncalibrated separable (SVPA) and calibrated (FADAPT) approaches (Fig. 3). The calibrated approach used MARMAP catch-per-effort (CPE) that was broken into gear- and age-specific values comparable to development of the fishery-dependent catch matrix (Table 5).

FADAPT requires input of the age-specific availability of each age in the index, so ages greater than or equal to the modal age were set to one, and for ages younger than the modal age, the CPE for that age was divided by the CPE for the modal age. Estimates of F for age 0 were always less than 0.001, while ages 4 through 7 were assumed fully recruited and F was averaged over these ages weighted by catch in numbers for those ages (referred to as full F).

Using the uncalibrated separable approach (SVPA) with M of 0.3, annual estimates of F (ages 1, 2, 3, 4+) tended to be higher for the period 1979-1985 (mean of 1.1 for full F) compared the periods 1986-1990 and 1991-1995 (mean of 0.8 for full F for both periods) (Fig. 3a, Table 6). The calibrated approach (FADAPT) with M of 0.3 showed similar means to the SVPA (1.1 for 1979-1985, 0.9 for full F during 1986-1990 and 1.0 for full F during 1991-1995) (Fig. 3b, Table 7).

Both VPA approaches were conducted with M equal to 0.2 and 0.4 (Fig. 4). Estimates of fishing mortality on fully recruited ages show a small and consistent bias. Full F is underestimated if M is overestimated (e.g., if M = 0.2 instead of assumed M = 0.3), and full F is overestimated if M is underestimated (e.g., if M = 0.4 instead of assumed M = 0.3).

Because virtual population analyses works backwards from an assumed or starting F for the oldest age of a cohort to the youngest age, confidence in estimated F (or population size) was least for the most recent estimate and converges towards "truth" for the youngest ages. Estimates generally converged within about

2 to 3 years. Fully recruited fishing mortality rates (age 4+) were compared for analyses based on catch matrices restricted to earlier final years (1990-1994) to analysis based on complete catch matrix (1995) to determine whether there was any consistent bias (Fig. 5). There was a large consistent bias that overestimates F in the most recent year (especially for the FADAPT approach). Slightly lower mean values of full F were obtained from both the SVPA and FADAPT approaches when 1995 was excluded from the third period (1991-1994; 0.9 from SVPA and 0.7 from FADAPT). Subsequent population-level analyses were based on averaging instantaneous fishing mortality rates for three time periods: 1979-1985, 1986-1990, and 1991-1995 (Table 6 and 7).

In using FADAPT, the program was allowed to estimate the relative weighting among the fishery-independent indices used in the calibration process. Weighting varied on slightly among the different FADAPT runs with varying M, yielding weights of 0.10 for hook-and-line, 0.29 for blackfish trap, 0.14 for Florida snapper trap, and 0.48 for Chevron trap. The small weight associated with the hook-and-line gear reduces the impact of the large drop in CPE that occurred between 1987 and 1988, which is not observed in the CPE associated with either the blackfish or Florida snapper gear (Fig. 1b).

A comparison is made based on using only the hook-and-line index, or only the trap indices (with FADAPT estimating weights of 0.31 for Blackfish, 0.15 for Florida Snapper, and 0.54 for Chevron traps) (Fig. 6). The sharp increase in F in the most recent year is driven largely by the small values of the hook-and-line index in recent years Fig. 6a). Trap indices cause lower values of F in recent years (mostly 1994 and 1995). The moderate increase in CPE for the Chevron trap from 1993 through 1995 is likely causing the increase in recruitment in 1995 noted in Fig. 6b, although the FADAPT run using only hook-and-line CPE for calibration shows some upturn in recruitment in 1995 as well.

Output from the SVPA and FADAPT approaches generally show similar results with the greatest divergence in the most recent year (Fig. 7). This divergence is most pronounced in 1995 with estimated recruits to age 1, and smaller divergence for estimated full F and total biomass (weight of fish in population over ages 1 through 7).

Yield per Recruit. Estimates of equilibrium yield per recruit are summarized for the SVPA (Table 8) and FADAPT (Table 9) approaches for different levels of M and three time periods (1979-1985, 1986-1990, and 1991-1994). Because of the bias observed in estimated F for 1995 (Fig. 6a), estimates of F for 1995 were not included in calculations for the late time period. Increasing natural mortality led to decreasing yield per recruit. A comparison of yield per recruit plotted against full fishing mortality (ages 4-7) for different ages at entry (FADAPT) showed only slight differences between the three time periods (Fig. 8). Two traditional biological reference points obtained from the yield per recruit approach are F_{max} and $F_{0.1}$ (Sissenwine and Shepherd 1987). Using estimates of F (with M of 0.3) from both VPA approaches, these reference points were estimated as F_{max} = 0.8 and $F_{0.1}$ = 0.4 for fully recruited ages (Table 10).

Spawning Potential Ratio. Estimates of equilibrium spawning potential ratio using estimated F (Table 6 and 7) from the two VPA approaches are summarized by time period and assumed level of M (Table 8 and 9). Because of the bias observed in estimated F for 1995 (Fig. 6a), estimates of F for 1995 were not included in calculations for the late time period. Estimated equilibrium SPR are compared between the two VPA approaches, showing increasing divergence beginning about 1988 (when the hook-and-line index dropped precipitously) (Fig. 7d). Using FADAPT VPA estimates of F (with M of 0.3) for three periods, SPR estimates based on total mature biomass, female biomass, and male biomass are compared (Fig. 9). Mature female biomass is less affected by increasing F than mature male biomass, precisely because the younger fish are predominantly females and the older fish are males. Full F that would produce an estimated 30% SPR was found to be greater than 2.5 for mature female biomass, 0.7 for total mature biomass, and 0.4 for mature male biomass (Table 10).

Corresponding estimates were made of the reduction in proportion of males in the population for three periods (Fig. 9; RATIO). For example, a value of 60% under 'Percent Male' (Table 8 and 9) implies that if the proportion of males in the unfished population (all mature ages) were 50%, then the introduction of fishing mortality would reduce this proportion to 30% (60% of 50%). If the initial proportion were 10%, then a reduction of 60% would reduce the proportion of males to 6%.

Discussion and Management Implications

Compared to several other assessments [e.g., red drum (Vaughan 1996), and red porgy (Vaughan et al. 1992)], the data for U.S. southern Atlantic black sea bass are quite good. As in Vaughan et al. (1995), only indirect estimation of commercial length frequency distributions for hook-and-line and traps for 1979-1983 from MARMAP data was necessary to fill a data gap.

The use of 5% post-release mortality may be low (Collins, in press). As noted in Vaughan et al. (1995), increasing the post-release mortality from 5% to 25% would increase their contribution to the total landings from 1% to 6%. Error of this magnitude is not likely to change the results significantly.

A major problem for many stock assessments is obtaining good estimates of natural mortality (M). The estimate of 0.3 used for black sea bass was based on life history analogy (Pauly 1979, Hoenig 1983). This value was used for the stock north of Cape Hatteras in 1991 (NEFSC 1991), but subsequently decreased to 0.2 (SARC 1996). In the SARC (1996), a maximum age of 15 is referenced, which would imply M of 0.28 according to Hoenig (1983). Sensitivity of F to M (Fig. 4) does not suggest any large bias for small errors in M.

Low (1981) obtained estimates of F ranging from 0.3 to 0.5 (or Z ranging from 0.6 to 0.8 with an M of 0.3) from data collected with traps off South Carolina in 1978 and 1979. Wenner et al. (1986) obtained higher estimates of Z, based on trap catch curve analysis, ranging from 0.7 in 1978 to 1.3 in 1981, and for hook-and-line ranging from 0.7 in 1979 to 1.4 in 1981. Our annual estimates of Z from catch curve analysis on fishing years agreed moderately well with estimates obtained by Low (1981) and Wenner et al. (1986); e.g., 0.8 in 1979 and 1.1 in 1981. Estimates of Z (full F + M) from the two VPA approaches were higher (1.4 in 1979 and 1.3 in 1981 for SVPA and 1.2 in 1979 and 1.4 in 1981 for FADAPT with M of 0.3). Estimates from the VPA approaches are generally more accurate than from catch curves, because they combine information across fishing years and are not based on an equilibrium assumption.

A major bias is associated with estimating fishing mortality (F) in the most recent year, but this bias as shown in the retrospective analyses is principally associated with the most recent year (Fig. 5). In spite of this estimation problem, declining trends in headboat CPE and in CPE from MARMAP sampling (especially hook-and-line gear) (Fig. 1), combined with the observed decline in recruits to age 1 (other than the terminal year for FADAPT) (Fig. 7b), raise significant concerns about the possibility of overfishing.

Yield per recruit analysis was conducted to obtain two traditional biological reference points: F_{max} and $F_{0.1}$. Estimates for these two values are 0.8 and 0.4, respectively (for M = 0.3), which are similar to those obtained in Vaughan et al. (1995; 0.9 and 0.4, respectively). Much lower values of these reference points were obtained for the stock north of Cape Hatteras for the same level of M (0.3 and 0.2, respectively, NEFSC 1991). The new estimates are consistent between the two VPA approaches. Mean full F (0.7 for SVPA and 0.9 for FADAPT averaging over 1991-1994; Table 10) are similar to F_{max}, but about double $F_{0.1}$. Estimated full F for the early period (1.1 for 1979-1985) is above both reference points, while estimates for the middle period (0.8-0.9 for 1986-1990) are greater than $F_{0.1}$.

Estimates of equilibrium SPR based on female biomass and egg production are higher than 40%, which is greater than the 30% biological reference point used to define overfishing by the South Atlantic Fishery Management Council (SAFMC 1991). However, black sea bass are protogynous hermaphrodites with most sea bass functioning initially as females and then as males. Hence, increasing fishing mortality on all ages reduces the proportion of mature males to mature females. Whether this will alter the age (and length) of transition is not known, and it was not possible to account for the effect of population density on transformation rate in population models. It has been suggested that males are currently not limiting, but the degree to which increasing fishing mortality can cause them to become limiting is unknown. Increased rate of transformation from females to males due to reduced abundance of males, which has been reported in other protogynous reef fish (Shapiro 1979), would lead to additional declines in mature female biomass. If females do not transform at a greater rate when the population is depressed, then the complementary concern may arise as to whether sufficient numbers of mature males will be present during spawning.

The modal values of age-specific mature female biomass, egg production, and mature male biomass are shifted to younger age with increasing F (Vaughan et al. 1995). Hence, the greatest effect of increasing F would be on males. This is because fewer older fish remain with higher F, and most older fish are males. Thus, estimates of SPR for males are smaller than for females. Estimates of SPR based on mature male biomass ranged between 13% and 20%.

The proportion of mature males relative to mature females is expected to be reduced to about 60% from fishing mortality for M of 0.3, which is not obviously suggestive that there will be insufficient numbers of males for the spawning process. Estimates of SPR for total mature biomass, recommended biological reference point in Vaughan et al. (1992, 1995), were generally found to be in the range of 21% to 31%. A full F of 0.7 will provide an estimate of SPR of about 30% (similar to F_{max}).

Vaughan et al. (1992, 1995) suggested using total mature population biomass as a measure of spawning potential for protogynous species, which for black sea bass produces an estimate of 25% for 1979-1985, 27% for 1986-1990. and 26% for 1991-1995 (Table 9, for M of 0.3 using FADAPT). These values are below the value 30% typically used by the South Atlantic Fishery Management Council to define overfishing for the snapper-grouper complex of species (SAFMC 1991), although it should be noted that the value of 26% for the recent period is undoubtedly somewhat underestimated as suggested by the retrospective analysis. Whether 30% remains the relevant value for the biological reference point when SPR is estimated from total mature biomass is a separate issue.

The U.S. southern Atlantic black sea bass stock is probably in better condition than many sympatric reef species despite heavy fishing pressure. This is probably because of earlier age of maturity for females (about 50% at age 1) and later age of full recruitment to the combined fisheries (at about age 4). Although retrospective analyses clearly suggest that F is overestimated in the current year (and hence SPR would be underestimated), declining estimated recruitment, headboat CPE, and MARMAP CPE beginning in the mid-1980's raise significant concern of potential overfishing. Although the cause of this decline in recruitment is difficult to ascribe and may be largely environmentally driven, resultant lower productivity increases the risk of overfishing at this time.

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Literature Cited

Ansley, H. L. H. and C. D. Davis. 1981. Migration and standing stock of fishes associated with artificial and natural reefs on Georgia's outer continental shelf. Ga Dep. Natur. Resour., Brunswick. 38 pp.

Bugley, K. and G. Shepherd. 1991. Effect of catch-and-release angling on the survival of black sea bass. N. Am. J. Fish. Manage. 11:468-471.

Clay, D. 1990. TUNE: a series of fish stock assessment computer programs written in FORTRAN for microcomputers (MS DOS). Int. Comm. Conserv. Atl. Tunas, Coll. Vol. Sci. Pap. 32:443-460.

Collins, M. R. 1990. A comparison of three fish trap designs. Fish. Res. 9:325-332.

Collins, M. R. In press. Survival estimates for demersal reef fishes released by anglers. Proc. Gulf Carib. Fish. Inst.

Collins, M. R., and G. R. Sedberry. 1991. Status of vermilion snapper and red porgy stocks off South Carolina. Trans. Amer. Fish. Soc. 120:116-120.

Collins, M. R., S. B. Van Sant, D. J. Schmidt and G. R. Sedberry. In press. Age validation, movements, and growth rates of tagged gag (*Mycteroperca microlepis*), black sea bass (*Centropristis striata*), and red porgy (*Pagrus*). Proceedings of the ICLARM/EPOMEX International Workshop on Tropical Snappers and Groupers. Campeche, Mexico, 1993.

Dixon, R. L. and G. R. Huntsman. In press. Estimating catches and fishing effort of the southeast United States headboat fleet, 1972-1982. NOAA Tech. Rep. NMFS.

Doubleday, W. G. 1976. A least squares approach to analyzing catch at age data. Res. Bull. Int. Comm. Northw. Atl. Fish. 12:69-81.

Gabriel, W. L., M. P. Sissenwine and W. J. Overholtz. 1989. Analysis of spawning stock biomass per recruit: an example for Georges Bank haddock. N. Am. J. Fish. Manage. 9:383-391.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. Canadian Atl. Fish. Sci. Adv. Comm. (CAFSAC) Res. Doc. 88/29. 12 pp.

Gray, G. W., L. L. Kline, M. F. Osburn, R. J. Salz, D. A. Van Vorhees, and J. F. Witzig. 1994. MRFSS User's Manual: A Guide to the National Marine Fisheries Service Marine Recreational Fisheries Statistics Survey Database. Special Report No. 37, Atlantic States Marine Fisheries Commission, Washington, DC.

Gulf of Mexico SPR Management Strategy Committee. 1996. An evaluation of the use of SPR levels as the basis for overfishing definitions in Gulf of Mexico finfish fishery management plans. Report to Gulf of Mexico Fishery Management Council, 6 May 1996. 46 pp.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull., U.S. 82:898-903.

Low, R. A., Jr. 1981. Mortality rates and management strategies for black sea bass off the southeast coast of the United States. N. Am. J. Fish. Manage. 1:93-103.

Mace, P. M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Can. J. Fish. Aquat. Sci. 41:110-122.

Mace, P. M., and M. P. Sissenwine. 1993. How much spawning per recruit is enough? Can. Spec. Publ. Fish. Aquat. Sci. 120:101-118.

Mercer, L. P. 1989. Species profile: Life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) -- Black sea bass. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.99); and U.S. Army Corps Engin., TR EL-82-4. 16 pp.

Murphy, G. I. 1965. A solution of the catch equation. J. Fish. Res. Board Can. 22:191-201.

Pauly, D. 1979. On the inter-relationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons. 39:175-192.

Pope, J. G. and J. G. Shepherd. 1982 A simple method for the consistent interpretation of catch-at-age data. J. Cons. 40:176-184.

Pope, J. G. and J. G. Shepherd. 1985. A comparison of the performance of various methods for tuning VPAs using effort data. J. Cons. 42:129-151.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can.

191:1-382.

SAS Institute Inc. 1987. SAS/STAT guide for personal computers. Version 6 Ed. SAS Institute Inc., Cary, NC. 1028 pp.

Shapiro, D. Y. 1979. Social behavior, group structure, and the control of sex reversal in hermaphroditic fish. Adv. Stud. Behav. 10:43-102.

Shepherd, G. 1991. Meristic and morphometric variation in black sea bass north of Cape Hatteras. N. Am. J. Fish. Manage. 11:139-148.

Sissenwine, M. P., and J. G. Shepherd. 1987. An alternative perspective on recruitment overfishing and biological reference points. Can. J. Fish. Aquat. Sci. 44:913-918.

South Atlantic Fishery Management Council (SAFMC). 1991. Amendment Number 4, regulatory impact review, initial regulatory flexibility analysis and environmental assessment for the fishery management plan for the snapper grouper fishery of the South Atlantic region. South Atlantic Fishery Management Council, Charleston, SC. 87 pp.

Stock Assessment Review Committee (SARC). 1996. Report of the 20th Northeast Regional Stock Assessment Workshop (20th SAW). Northeast Fisheries Science Center Reference Document 95-18, Woods Hole, MA. 211 pp.

U.S. National Marine Fisheries Service, Northeast Fisheries Science Center (NEFSC). 1991. Status of the fisheries resources off the northeastern United States for 1991. NOAA Tech. Memo. NMFS-F/NEC-86. 132 pp.

U.S. National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC). 1995. Status of fishery resources off the southeastern United States for 1993. NOAA Tech. Memo. NMFS-SEFSC-368. 72 pp.

Vaughan, D. S. 1996. Status of the red drum stock of the Atlantic coast: Stock assessment report for 1995. NOAA Tech. Memo. NMFS-SEFC-380. 50 pp.

Vaughan, D. S., M. R. Collins, and D.J. Schmidt. 1995. Population characteristics of the black sea bass _Centropristis striata_ from the southeastern U.S. Bull. Mar. Sci. 56:250-267.

Vaughan, D. S., G. R. Huntsman, C. S. Manooch III, F. C. Rohde and G. F. Ulrich. 1992. Population characteristics of the red porgy, _Pagrus_, stock off the Carolinas. Bull. Mar. Sci. 50:1-20.

Vaughan, D. S. and P. Kanciruk. 1982. An empirical comparison of estimation procedures for the von Bertalanffy growth equation. J. Cons. 40:211-219.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Hum. Biol. 10:181-213.

Wenner, C. A., W. A. Roumillat and C. W. Waltz. 1986. Contributions to the life history of black sea bass, _Centropristis striata_, off the southeastern United States. Fish. Bull., U.S. 84:723-741.

Table 1. U.S. southern Atlantic black sea bass sex composition by age, 1978-1982.

Age (yr)	Proportion		
	Female	Transition	Male
0	0.849	0.015	0.136
1	0.829	0.072	0.099
2	0.686	0.166	0.148
3	0.571	0.227	0.202
4	0.369	0.241	0.390
5	0.187	0.193	0.620
6	0.119	0.117	0.764
7+	0.093	0.103	0.804

Table 2. U.S. southern Atlantic black sea bass landings in weight and numbers by fishery caught between Cape Hatteras, NC, and Miami, FL, 1979-1995.

Year	Commercial	Recreational	Headboat	Total
		Thousands of Pounds		
1979	859.1	987.4	586.7	2433.2
1980	1050.6	1891.4	643.6	3585.6
1981	1240.1	333.6	711.3	2285.0
1982	974.3	1178.6	735.5	2888.4
1983	664.8	464.8	723.9	1853.5
1984	645.2	1463.7	693.2	2802.1
1985	599.8	941.1	595.7	2136.6
1986	710.0	473.4	562.9	1746.3
1987	597.2	1009.1	646.5	2252.8
1988	815.4	1467.8	635.2	2918.4
1989	825.0	1180.2	478.0	2483.2
1990	1027.5	614.8	379.6	2021.9
1991	944.2	771.7	286.2	2002.1
1992	836.6	617.0	215.9	1659.5
1993	768.0	529.3	143.0	1440.3
1994	800.0	635.3	132.4	1567.7
1995	607.5	589.5	127.6	1324.6
		Thousands of Fish		
1979	813.2	2593.0	904.6	4310.8
1980	1050.5	2011.9	1172.5	4234.9
1981	1376.7	736.0	710.6	2823.3
1982	1142.4	2242.3	1238.9	4623.6
1983	776.9	1185.8	723.3	2686.0
1984	743.2	1998.2	692.6	3343.0
1985	679.1	1780.0	595.2	3054.3
1986	789.7	1053.3	562.4	2405.4
1987	609.4	1501.5	673.7	2784.6
1988	912.0	1582.6	1028.0	3522.6
1989	1197.5	1294.4	765.1	3257.0
1990	1476.9	773.0	658.6	2908.5
1991	1086.8	972.0	506.3	2565.1
1992	1037.6	866.7	386.0	2290.3
1993	986.6	638.8	213.8	1839.2
1994	859.2	714.1	208.1	1781.4
1995	601.8	618.2	190.3	1410.3

Table 3. Estimated parameters for von Bertalanffy growth equation with U.S. southern Atlantic black sea bass data from 1978-1995. Standard error given parenthetically below estimate [$TL(in) = L_\infty(1 - \exp(-k(age - t_0)))$]. Sex-based growth equations based on data from 1978-1982 inclusive.

Type	n	L_∞	k	t_0
		Unweighted Data		
All	17729	32.50 (1.54)	0.077 (0.005)	-1.44 (0.07)
		Weighted Data[a]		
All	17729	18.31 (0.08)	0.229 (0.003)	-0.26 (0.03)
Female	5518	28.74 (1.27)	0.070 (0.005)	-2.23 (0.12)
Trans	2161	18.60 (0.34)	0.176 (0.010)	-1.28 (0.13)
Male	3202	17.54 (0.14)	0.265 (0.009)	-0.24 (0.06)

[a] Weighted by inverse of number of fish at each age.

Table 4. U.S. southern Atlantic black sea bass catch-in-numbers-at-age (in thousands) matrices for ages 1 through 8+ (and total numbers) and years 1979 through 1995. Total catch in weight (thousands of pounds) are also presented. Note that 5% of catch-release recreationally caught fish (type B2 fish from MRFSS) are included in estimates by number (modal age underlined).

Year	Age (yr)									Number	Weight
	0	1	2	3	4	5	6	7	8+	(1000)	(1000 lbs)
1979	2.4	303.2	1381.4	1250.2	710.5	360.2	229.2	54.7	19.1	4310.9	2433.2
1980	7.8	160.3	799.1	1715.1	1016.9	321.3	149.5	34.3	30.6	4234.9	3585.6
1981	6.4	232.4	632.2	819.7	729.2	278.2	83.9	29.9	11.6	2823.4	2285.0
1982	6.0	246.8	1213.9	1539.7	1236.1	264.0	95.6	17.5	3.9	4623.6	2888.4
1983	3.0	293.0	795.7	837.5	522.5	206.8	22.6	3.8	1.2	2686.0	1853.5
1984	5.8	54.5	388.6	1098.2	1298.4	436.3	139.7	10.6	1.9	3434.0	2802.1
1985	23.8	350.4	616.7	984.6	791.4	240.7	42.5	3.0	1.0	3054.3	2136.6
1986	0.0	126.5	891.6	547.4	505.4	270.5	52.6	9.2	2.2	2405.4	1746.3
1987	0.0	228.0	686.0	1012.7	512.6	252.3	67.5	23.6	1.9	2784.7	2252.8
1988	3.3	71.8	727.4	1024.1	1122.3	397.4	124.0	47.2	5.1	3522.5	2918.4
1989	4.4	83.0	470.5	1191.6	1010.5	395.5	74.9	17.6	9.1	3257.0	2483.2
1990	0.0	38.9	556.9	1134.3	685.1	329.2	124.8	32.5	6.8	2908.5	2021.9
1991	0.0	52.2	637.9	1001.5	505.6	275.9	72.2	14.0	6.0	2565.1	2002.1
1992	0.0	11.2	489.1	893.9	491.8	316.2	74.7	4.8	8.6	2290.3	1659.5
1993	0.1	25.0	383.0	829.5	344.9	184.4	59.5	6.0	6.8	1839.3	1440.3
1994	0.0	10.4	183.3	397.3	832.8	217.6	116.8	15.8	7.2	1781.3	1567.7
1995	0.0	8.4	219.8	411.5	336.0	309.1	111.8	8.7	5.0	1410.3	1324.6

Table 5. U.S. southern Atlantic black sea bass catch-per-effort in numbers-at-age from different MARMAP gears for ages 1 through 8+ (and total numbers) available for years 1979 through 1995 (modal age underlined).

Year	Age (yr)									CPE
	0	1	2	3	4	5	6	7	8+	
					Hook-and-Line					
1979	0.02	1.87	9.80	10.71	5.26	2.41	1.81	0.47	0.14	32.50
1980	0.02	0.43	3.53	9.61	5.82	1.98	0.90	0.21	0.08	22.59
1981	0.0	0.65	6.40	8.31	4.85	1.29	0.29	0.10	0.03	21.92
1982	0.0	2.05	14.49	12.94	8.97	1.63	0.61	0.13	0.03	40.86
1983	0.01	2.92	13.88	11.22	4.98	1.97	0.29	0.09	0.02	35.38
1984	0.0	0.35	11.28	20.92	9.95	2.93	0.84	0.05	0.0	46.31
1985	0.02	2.02	5.91	10.54	5.91	1.79	0.32	0.03	0.01	26.55
1986	0.0	1.18	8.05	5.73	4.77	2.30	0.37	0.12	0.01	22.52
1987	0.0	2.93	6.95	8.11	3.39	1.42	0.21	0.05	0.0	23.07
1988	0.0	0.29	1.47	1.22	0.79	0.22	0.05	0.02	0.0	4.07
1989	0.0	0.22	1.26	1.77	0.90	0.25	0.03	0.0	0.0	4.43
1990	0.0	0.17	1.44	2.27	1.14	0.48	0.18	0.03	0.0	5.70
1991	0.0	0.46	1.24	1.25	0.56	0.22	0.03	0.01	0.0	3.75
1992	0.0	0.31	2.48	2.21	0.95	0.48	0.07	0.0	0.0	6.50
1993	0.0	0.95	2.80	2.76	0.82	0.41	0.11	0.01	0.0	7.85
1994	0.0	0.27	1.21	0.99	1.33	0.18	0.07	0.01	0.0	4.06
1995	0.0	0.20	1.34	1.05	0.54	0.32	0.06	0.0	0.0	3.50

Table 5. (cont.)

Year	Age (yr)									CPE
	0	1	2	3	4	5	6	7	8+	
Blackfish Trap										
1979	0.0	0.10	1.41	2.85	1.47	0.62	0.35	0.08	0.03	6.91
1980	0.0	0.02	0.58	3.49	2.32	0.60	0.21	0.04	0.01	7.27
1981	0.0	0.06	1.62	3.43	2.36	0.60	0.13	0.04	0.01	8.25
1982	0.0	0.29	2.45	2.50	1.56	0.20	0.04	0.01	0.0	7.06
1983	0.0	0.28	2.80	2.74	0.94	0.37	0.04	0.01	0.0	7.17
1984	0.0	0.04	1.13	3.55	1.43	0.38	0.09	0.0	0.0	6.64
1985	0.0	0.23	1.09	4.07	2.28	0.65	0.11	0.01	0.0	8.44
1986	0.0	0.18	1.86	1.88	1.42	0.64	0.09	0.02	0.0	6.08
1987	0.0	0.33	1.72	3.07	1.12	0.44	0.05	0.01	0.0	6.73
1988	0.0	0.09	0.83	1.09	0.91	0.25	0.05	0.02	0.0	3.25
1989	0.0	0.05	0.64	1.50	0.97	0.23	0.03	0.01	0.0	3.43
Florida Snapper Trap										
1980	0.0	0.38	3.34	7.43	2.92	0.59	0.20	0.04	0.01	14.91
1981	0.0	0.20	2.68	3.35	2.06	0.58	0.15	0.05	0.02	9.08
1982	0.0	2.05	10.66	5.62	3.15	0.37	0.12	0.02	0.0	21.99
1983	0.0	1.25	6.07	3.15	1.07	0.42	0.06	0.01	0.0	12.04
1984	0.0	0.76	5.02	4.29	1.16	0.31	0.08	0.00	0.0	11.62
1985	0.01	2.06	5.64	5.90	2.30	0.72	0.15	0.02	0.0	16.80
1986	0.01	0.96	5.42	2.18	1.42	0.67	0.09	0.01	0.0	10.75
1987	0.0	2.05	3.72	2.95	0.90	0.30	0.03	0.0	0.0	9.94
1988	0.01	0.58	2.51	1.42	0.55	0.16	0.04	0.02	0.0	5.29
1989	0.0	0.15	1.06	1.01	0.50	0.16	0.02	0.0	0.0	2.90

Table 5. (cont.)

Year	Age (yr)									CPE
	0	1	2	3	4	5	6	7	8+	
Chevron Trap										
1988	0.01	1.10	<u>5.63</u>	3.99	1.80	0.40	0.07	0.03	0.0	13.04
1989	0.0	0.30	4.68	<u>4.91</u>	2.07	0.48	0.08	0.02	0.0	12.54
1990	0.0	0.99	5.22	<u>5.47</u>	1.97	0.70	0.24	0.04	0.0	14.65
1991	0.0	1.99	<u>5.55</u>	3.42	1.26	0.37	0.03	0.01	0.0	12.62
1992	0.0	0.50	<u>5.19</u>	3.64	1.38	0.60	0.10	0.0	0.0	11.42
1993	0.0	1.12	<u>3.07</u>	2.05	0.46	0.19	0.05	0.0	0.0	6.95
1994	0.0	0.41	<u>3.57</u>	2.17	2.49	0.29	0.14	0.01	0.0	9.08
1995	0.0	1.38	<u>5.80</u>	2.10	0.88	0.44	0.06	0.01	0.0	10.66

Table 6. Mean estimates of age-specific instantaneous fishing mortality rate (F) on U.S. southern Atlantic black sea bass for three time periods using separable virtual population analysis (SVPA). Corresponding exploitation rates given in parentheses [$u = F(1-e^{-Z})/Z$]. Estimates given for different assumed levels of natural mortality.

Natural Mortality M	Age (yr)			
	1	2	3	4+
		1979-1985		
0.2	0.03 (0.03)	0.24 (0.20)	0.62 (0.42)	1.20 (0.64)
0.3	0.02 (0.02)	0.21 (0.16)	0.55 (0.37)	1.11 (0.59)
0.4	0.02 (0.01)	0.17 (0.13)	0.49 (0.32)	1.01 (0.53)
		1986-1990		
0.2	0.02 (0.02)	0.17 (0.14)	0.43 (0.32)	0.84 (0.52)
0.3	0.01 (0.01)	0.14 (0.11)	0.38 (0.27)	0.76 (0.47)
0.4	0.01 (0.01)	0.11 (0.09)	0.32 (0.23)	0.67 (0.41)
		1991-1995		
0.2	0.02 (0.02)	0.17 (0.14)	0.43 (0.32)	0.86 (0.53)
0.3	0.01 (0.01)	0.14 (0.11)	0.36 (0.27)	0.76 (0.47)
0.4	0.01 (0.01)	0.11 (0.08)	0.31 (0.22)	0.66 (0.41)

Table 7. Mean estimates of age-specific instantaneous fishing mortality rate (F) on U.S. southern Atlantic black sea bass for three time periods using FADAPT virtual population analysis. Corresponding exploitation rates given in parentheses [$u = F(1-e^{-Z})/Z$]. Estimates given for different assumed levels of natural mortality.

Natural Mortality M	Age (yr)			
	1	2	3	4+
		1979-1985		
0.2	0.04 (0.04)	0.22 (0.18)	0.55 (0.37)	1.15 (0.62)
0.3	0.03 (0.03)	0.18 (0.15)	0.48 (0.33)	1.06 (0.57)
0.4	0.03 (0.02)	0.15 (0.12)	0.43 (0.28)	0.97 (0.52)
		1986-1990		
0.2	0.02 (0.02)	0.19 (0.16)	0.48 (0.35)	0.97 (0.56)
0.3	0.02 (0.02)	0.16 (0.13)	0.43 (0.30)	0.89 (0.51)
0.4	0.01 (0.01)	0.13 (0.10)	0.38 (0.26)	0.82 (0.46)
		1991-1995		
0.2	0.01 (0.01)	0.20 (0.17)	0.56 (0.39)	1.03 (0.59)
0.3	0.01 (0.01)	0.18 (0.14)	0.50 (0.34)	0.96 (0.54)
0.4	0.01 (0.00)	0.15 (0.12)	0.45 (0.30)	0.89 (0.49)

Table 8. Equilibrium yield per recruit (YPR) and spawning potential ratio (SPR) of U.S. southern Atlantic black sea bass based on mean age-specific fishing mortality rates for three periods (1979-1985, 1986-1990 and 1991-1994) from separable virtual population analysis (SVPA). Estimates based on separate Von Bertalanffy growth parameters for females and males.

Natural Mortality	YPR (lbs)	Spawning Potential Ratio				Percent Male[a]
		Total	Female	Eggs	Male	
			1979-1985			
0.2	0.35	13	35	42	7	50
0.3	0.27	24	51	56	13	60
0.4	0.20	37	62	67	22	68
			1986-1990			
0.2	0.38	16	40	47	9	54
0.3	0.27	29	57	62	18	64
0.4	0.19	43	69	73	28	72
			1991-1994			
0.2	0.38	17	40	47	10	54
0.3	0.27	30	57	63	18	64
0.4	0.19	44	69	74	29	73

[a] Percent relative reduction in numbers of mature males between fished and unfished conditions.

Table 9. Equilibrium yield per recruit (YPR) and spawning potential ratio (SPR) of U.S. southern Atlantic black sea bass based on mean age-specific fishing mortality rates for three periods (1979-1985, 1986-1990, and 1991-1994) from FADAPT virtual population analysis. Estimates based on separate Von Bertalanffy growth parameters for females and males.

Natural Mortality	YPR (lbs)	Spawning Potential Ratio Total	Female	Eggs	Male	Percent Male[a]
		1979-1985				
0.2	0.36	14	36	43	7	51
0.3	0.27	25	52	57	14	60
0.4	0.20	37	63	68	23	69
		1986-1990				
0.2	0.37	15	38	45	8	53
0.3	0.27	27	54	60	16	62
0.4	0.19	40	66	70	25	71
		1991-1994				
0.2	0.37	15	38	45	8	52
0.3	0.27	26	53	59	15	61
0.4	0.20	39	65	70	24	70

[a] Percent relative reduction in numbers of mature males between fished and unfished conditions.

Table 10. Biological reference points developed from equilibrium yield per recruit (YPR) and spawning potential ratio (SPR) analyses for U.S. southern Atlantic black sea bass estimated from output from FADAPT (with corresponding SVPA estimates in parenthesis).

Biological Reference Point	Natural Mortality (M) 0.2	0.3	0.4
YPR:			
$F_{0.1}$	0.3 (0.3)	0.4 (0.4)	0.5 (0.5)
F_{max}	0.5 (0.4)	0.8 (0.8)	1.4 (1.4)
SPR:			
Female:			
F_{10}	>2.5 (>2.5)	>2.5 (>2.5)	>2.5 (>2.5)
F_{20}	>2.5 (>2.5)	>2.5 (>2.5)	>2.5 (>2.5)
F_{30}	1.8 (1.8)	>2.5 (>2.5)	>2.5 (>2.5)
Male:			
F_{10}	0.8 (0.8)	1.6 (1.7)	>2.5 (>2.5)
F_{20}	0.4 (0.4)	0.7 (0.7)	1.1 (1.2)
F_{30}	0.2 (0.2)	0.4 (0.4)	0.6 (0.6)
Total:			
F_{10}	2.1 (2.1)	>2.5 (>2.5)	>2.5 (>2.5)
F_{20}	0.6 (0.6)	1.6 (1.7)	>2.5 (>2.5)
F_{30}	0.3 (0.3)	0.7 (0.7)	1.7 (1.7)
Observed Full F by Period:			
1979-85	1.1 (1.2)	1.1 (1.1)	1.0 (1.0)
1986-90	1.0 (0.8)	0.9 (0.8)	0.8 (0.7)
1991-95	1.0 (0.9)	1.0 (0.8)	0.9 (0.7)
(1991-94)	1.0 (0.8)	0.9 (0.7)	0.8 (0.6)